COMPARISON OF PLUG-IN GAIT AND A SIX DEGREES OF FREEDOM MODEL FOR ESTIMATING KNEE KINEMATICS DURING A DOUBLE LEG DROP JUMP

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Biomechanical models allow for a comprehensive understanding of dynamic movements that could be used to assess athletic performance or identify injury risk and return to play status. In order to make clinical recommendations based on these model outputs, discrepancies between modelling approaches need to be identified. The purpose of this study was to compare the knee kinematics between the commonly used Plug-in Gait model and a six degrees of freedom model during the first landing a double leg drop jump (DLDJ). This study identified differences in the model outputs for knee kinematics, most prominently in the frontal and transverse planes. Further investigation is required to determine the reliability and sensitivity of these model outputs.

KEYWORDS: Six degrees of freedom model, Plug-in Gait, anterior cruciate ligament

INTRODUCTION: A biomechanical model is generated by tracking the three-dimensional trajectories of reflective markers attached to a person's body using an optical motion capture system. The markers are positioned on anatomical landmarks and specific reference points on the body which are then used to define the origin and orientation of the segments and joints. From this we can estimate lower limb joint kinematics and kinetics, for a comprehensive understanding of dynamic movements in improving athletic performance, identifying injury risk and determining an athlete's suitability to return-to-play. However, in order to make clinical recommendations based on the output of these models, we first need to ensure that they are valid and establish any discrepancies between modelling approaches.

One of the most commonly used biomechanical models is the "Newington" model (Davis et al., 1991), on which Vicon's Plug-in Gait (PiG) model is based. Although PiG was originally developed for gait analysis, in recent years its application has been broadened to the analysis of sporting movements (Hewett et al., 2005 and King et al., 2018). The model is widely used by clinical investigators due to the ease of application and processing. However, correct placement of the thigh and shank markers are critical in determining the alignment of the knee axis, with previous studies (Groen et al., 2012) demonstrating the high sensitivity of the model outputs to marker placement error. The six degrees of freedom model (6DoF) is an alternative model that requires a cluster of markers on each segment of the lower limb. Each cluster consists of at least three non-colinear markers attached to a rigid base (Collins et al., 2009). By using these clusters, it is possible to track each segment independently allowing 6DoF at each joint (rotational and translational). Additionally, the fixation of these clusters on a rigid plate strapped to the segment minimises the source of error from soft tissue artefacts (Cappozzo et al., 1991).

Previous comparison of these models has been limited to gait analysis (Collins et al., 2009 and Zuk et al., 2012). Therefore, evaluation between model outputs during sport movements is necessary to understand the implications of model choice for assessing sports performance or rehabilitation. With jumping and landing commonly used tasks in assessing an athlete's performance or rehabilitation status (Hewett et al., 2005), the aim of this study is to compare the knee kinematic outputs of the PiG and 6DoF model during a double leg drop jump (DLDJ).

METHODS: Twenty-three male athletes (mass 83.4 kg ± 11.38, height 1.81m ± 0.08) who had undergone anterior cruciate ligament reconstruction (ACLR) approximately 9 months previously took part in this study. All participants had stated their intention to return to play a multi-directional sport.
Forty-two reflective markers were placed on the participant's shoes and skin. The marker set (Figure 1) included: markers on anatomical locations that were necessary for both models, reference markers on the lower limb in accordance with the PiG model, cluster markers that were strapped to each thigh and shank in accordance with the 6DoF model, and calibration markers that were only present in the static trial and used to calculate joint widths. An additional six markers were used as a quality measure for data processing of the PiG model.

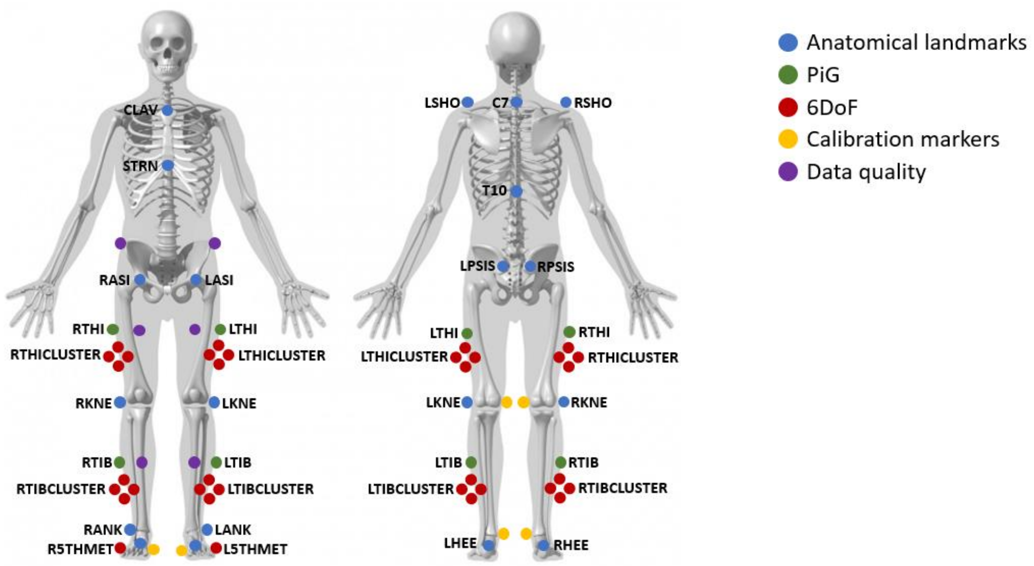

Figure 1: Representation of the marker set used.

Marker and ground reaction force data were captured using a 10-camera optical motion capture (200Hz; Bonita B10, Vicon Motion Systems Ltd, Oxford, UK) and force plate (1000Hz; AMTI, MA, USA) system. Prior to testing, all participants completed a standardised warm-up routine involving jogging and squats, as well as a static trial that would be used for applying the different modelling approaches. Participants then completed a battery of jumping and change of direction tasks as previously described (King et al., 2018). Only the three DLDJ trials for each participant were processed and analysed for this study.
Data were initially processed in Vicon software (Nexus 2.8.1, Vicon Motion Systems Ltd, Oxford, UK) to ensure that the initial pre-processing of the data was consistent for both models. This included gap filling and screening of the marker trajectories and application of a low-pass-filter using a zero-lag, fourth-order Butterworth filter (cut-off frequency of 15 Hz) on both the marker and force data. The datasets were then copied to create two versions of the pre-processed data. The PiG model was implemented using the Vicon software on one copy of the data and the other copy was imported into Visual 3D (v.500, C-Motion, Rockville MD) for implementation of the 6DoF model.
After implementation of the biomechanical models the kinematic outputs and force data were exported to MATLAB (MATLAB 2019a, The MathWorks Inc., MA, USA) for the final stages of processing and analysis. Knee kinematics were extracted during the first landing of the drop jump by identifying the start and end of the ground reaction force (>20N). The peak angle of the first landing was then identified for each trial, with the mean of each subject's three trials used for further analysis. The correlation coefficient of the mean peak angle between the PiG and 6DoF model was then calculated.

RESULTS: The correlation of the peak knee angle in the sagittal, frontal and transverse plane for both legs are shown in Figure 2.

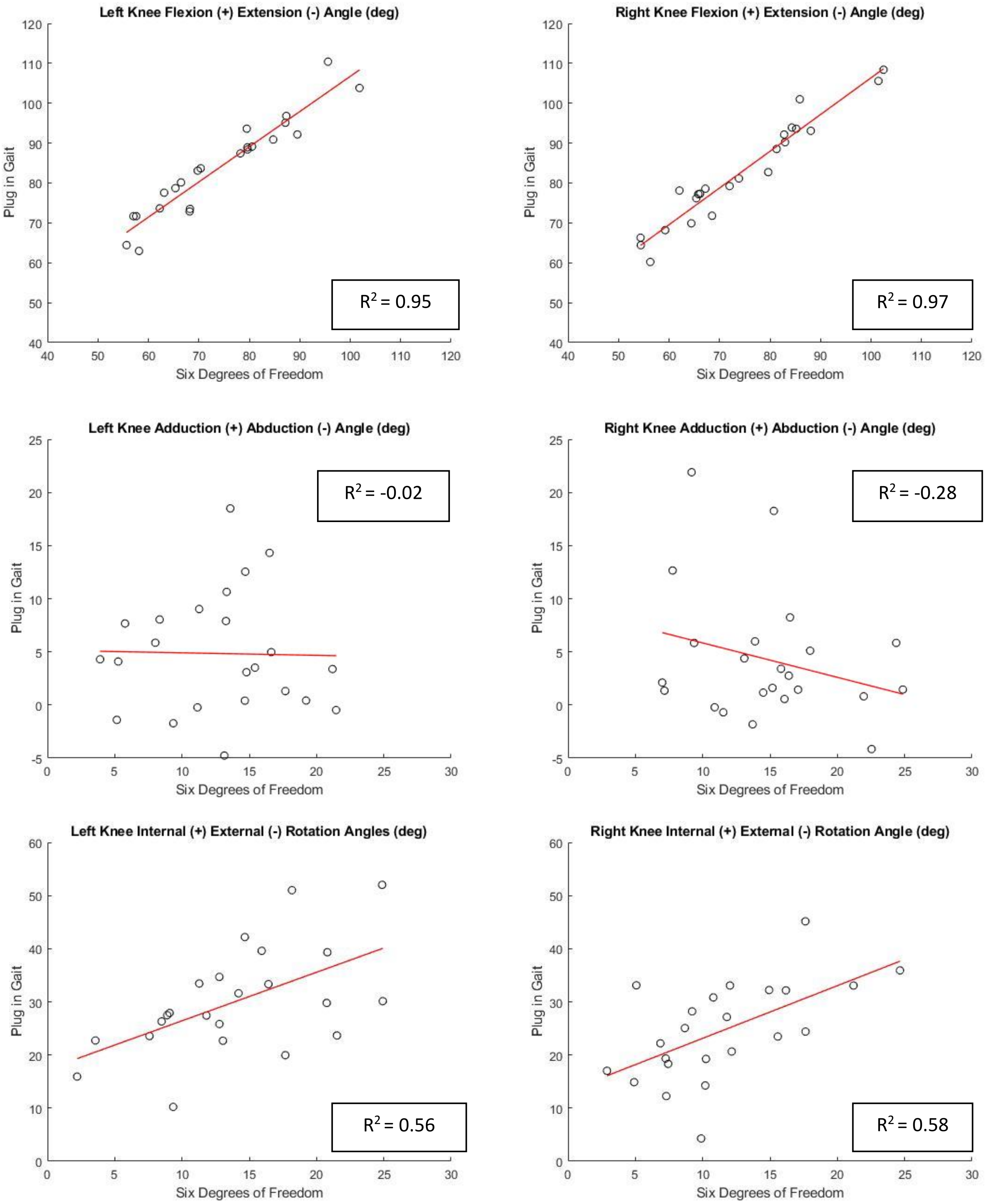

Figure 2: Correlation plots of peak knee angle during the first landing of the drop jump for both legs in the sagittal, frontal and transverse plane.

DISCUSSION: Correlations between joint angles calculated using the PiG model and the 6DoF model were strong in the sagittal plane, moderate in the transverse plane and poor in the frontal plane. The main discrepancies between model outputs are likely due to the different anatomical definitions used for the knee joint. The axis orientation of the joint is defined using the model's specific reference markers on each segment, explaining why the main differences in joint angle estimation between the two models was most prominent out of the sagittal plane. Furthermore, the error obtained from soft tissue artefacts between model outputs will differ due to the different placement methods of the reference markers. The poor correlation of the frontal knee angles (left leg R2= -0.02 and right leg R2= -0.28) and overestimation of the transverse knee angles in the PiG model are in agreement with previous studies (Groen et al., 2012) and can be associated to the high sensitivity of the PiG model to marker placement error.
When considering the application of these models, analysis of knee movement in the frontal plane is crucial in determining an athlete's performance and injury risk (Hewett et al., 2005). More recently a normal level of performance asymmetry between limbs (particularly frontal knee movement) has been associated with reduced risk of reinjury when returning to sports (King et al., 2019). With the clinical application of these models reliant on the frontal plane movement it is necessary to further investigate the sensitivity of this output between models and the influence this could have on clinical decision making.

CONCLUSION: This study identified differences in the model outputs for knee kinematics from the PiG and 6DoF, most prominently in the frontal and transverse planes. Further investigation is required to determine the reliability and sensitivity of these model outputs.

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ACKNOWLEDGEMENTS: The authors would like to thank and acknowledge the staff at the Sport Surgery Clinic, Dublin for their support, especially the Biomechanics team.